Dynamic self-assembly of magnetic microparticles: surface wave assisted magnetic exchange

Scientific Achievement

Researchers at Argonne National Laboratory have developed a new method for encouraging microscopic particles to self-assemble into desired complex patterns. Self-assembly, the spontaneous organization of materials into complex architectures constitutes one of the greatest prospects for nanoscience. The science underlying the formation of nanostructured materials via self assembly is largely driven by thermodynamic forces, which dictate the type of complex pattern formation. We present a new approach to self-assembly of nanoparticles which opens up the possibility of creating new self-assembled patterns unbridled by the forces of thermodynamics and hence providing an extra knob to tune the organized complex structures.

Our method is inspired by the patterns formed in shaken mixtures of much larger granular materials. It relies on the collective interactions between the particles due to long-range magnetic forces and hydrodynamic interactions with the surface of a liquid. Direct magnetic excitation of small particles offers unique new opportunities compared to traditional techniques. It enables one to deal with extremely fine magnetic powders which are not easily controlled by other means. We have demonstrated that granular media consisting of magnetic spherical microparticles suspended over a liquid/air interface and subject to transverse alternating magnetic field, self-assemble into novel magnetically ordered dynamic multi-segment structures ("magnetic snakes"). The properties of the resulting structures are controlled by the magnitude and frequency of the driving magnetic field as well as the properties of the liquid/air interface.

Significance

The discovery of a remarkably rich dynamic assembly of magnetic field driven magnetic micro-particles suspended on a fluid/air interface represents a significant breakthrough in our understanding of the complex physics of self-assembly. Our results exemplify the importance of the interactions between the particles and the hydrodynamic flows in the liquid excited by the collective response of the magnetic particles to an external magnetic driving force. Extension of our experiments towards self-assembly of magnetic submicron particles will have intriguing practical applications, such as lithographic patterning and self-assembly processing of magnetic nanopowders etc. Our work has attracted much attention from the broad scientific and industrial community. Our results were recently presented at two invited seminars: University of Chicago (The Materials Research Center Seminar, January 23, 2006); Illinois Tool Works Inc. (ITW Technology Center, August 11, 2005). This work was recently accepted for publication in Physical Review Letters (2006)
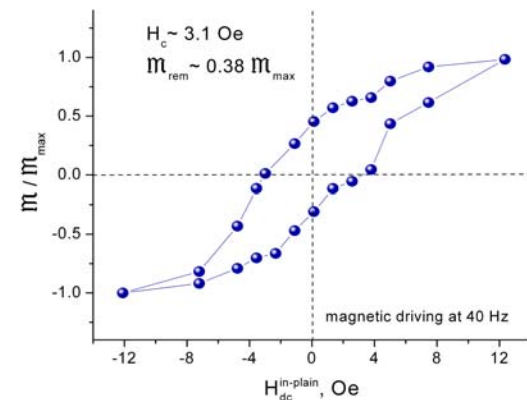
Performers

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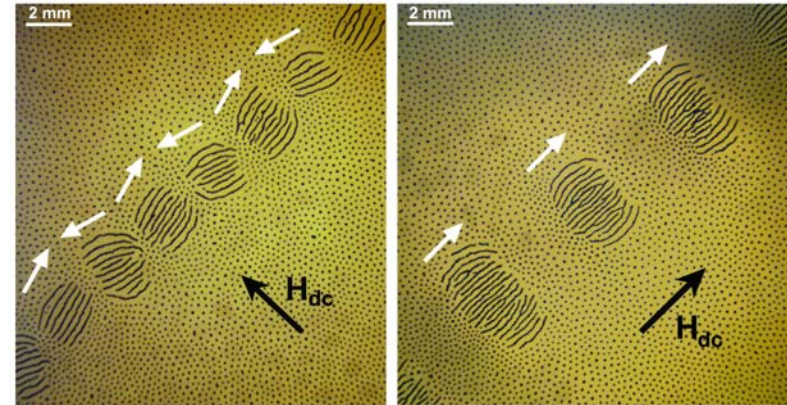## Dynamic self-assembled structures at the liquid/air interface
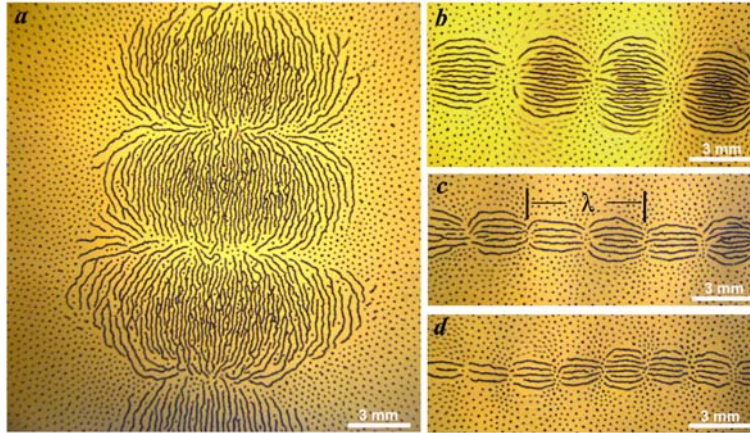
The size of the segments is determined by the magnetic field frequency

Magnetic properties of the generated structures

The segments of the "snake" exhibit long-range antiferromagnetic ordering between segments mediated by the surface waves, while each segment is composed of ferromagnetically ordered chains of microparticles.

$H_c \sim 3.1$ Oe
$m_{rem} \sim 0.38\ m_{max}$
magnetic driving at 40 Hz

The generated structures exhibit magnetic hysteretic behavior with respect to an external in-plane magnetic field

Future directions:

♦ Dynamic self-assembly of magnetic submicron and nano particles (effect of particle size reduction on the magnetically driven self-assembly)
♦ Effect of particle shape anisotropy on the dynamic self-assembly
♦ Mechanism of nonlinear flow generation in magnetically driven magnetic granular systems

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